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Subject Category: Criticality Hazards

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CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CHEMICALS CORPORATION
Y-12 AREA
Contract No. W-7405-eng-26

SUPERINTENDENT'S DEPARTMENT
Mr. L. B. Emlet, Y-12 Superintendent

RADIATION CONTROL GROUP
J. W. Morfitt, Supervisor

POTENTIAL HAZARDS OF CRITICALITY ACCIDENTS

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Criticality Hazards

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ABSTRACT

Accidental accumulations of super-critical masses of fissionable materials have resulted in radiation bursts ranging from a little less than 0.1 megawatt to more than 15 megawatts. The lethal radii for bursts of 0.1 megawatt, 3 and 15 megawatts are calculated to be approximately 1-1/2, 9-1/2, and 22 feet, respectively. These calculations are based on the assumption that 400 roentgens of gamma or gamma equivalent radiation is lethal to 50% of the population[5].

Although the residual radiation from the fission fragments is large, operating personnel outside of the lethal circle can remain in the contaminated area for as long as 20 to 30 sec. without adding significantly to their over-all exposure. For an accident of about 0.1 megawatt, probably less than 7 additional roentgens[1] will be received by remaining in the contaminated area for 20 sec. The additional radiation would be proportionally higher for bursts of from 3 to 15 megawatts. These approximations do not include the health hazard of ingested beta and alpha-active contaminants, which might be present in the air after a burst.

Process monitors with a sensitivity of .014 r/hr. such as used at Y-12 are more than adequate for full coverage of all likely bursts when placed on 100 foot centers.

[redacted]

POTENTIAL HAZARDS OF CRITICALITY ACCIDENTS

This paper uses the contents of several reports written on accidental bursts due to the accumulation of excess fissionable mass. It is hoped that this paper will shed some light on what might be expected should an accident occur in a fissionable material production facility.

The four questions discussed in this paper are:

1. What is the approximate magnitude of a burst?
2. What is the lethal radius of a given burst?
3. How much gamma radiation from fission products remain after a radiation burst?
4. Will a process monitor with a sensitivity of .014 r/hr. such as used at Y-12 detect a burst and what is its effective range?

In order to answer questions one and two, let us review some of the elementary aspects of the fission process.

The energy of nuclear fission is released as follows:(6)

Kinetic energy of the fragments	162 Mev.
Beta decay	5 "
Gamma decay	5 "
Neutrinos	11 "
Fission neutrons	6 "
Prompt gammas	6 "
Total	195 Mev.

[redacted]

Of the above total, only the gamma and fission neutrons will be considered as damaging radiation from a burst.

The gamma-ray dose can be computed as follows: If the gamma rays are emitted from a point source, the energy absorbed by 1 cm^3 air at a distance x from the point source is given by

$$(1) \qquad E = \frac{qh\nu}{4\pi x^2} e^{-ux} u$$

where q is the number of gamma quanta emitted, and u is the absorption coefficient of the gamma rays. Thus e^{-ux} represents the attenuation of the gammas by the intervening absorbing material, in this case air. The appropriate value for u is $3.5 \times 10^{-5}\ cm^{-1}$.

Equation (1) can be expressed in roentgens by dividing by the energy roentgen equivalent, 10.8×10^{-9} joules/r. Equation (1) then can be written

$$(2) \qquad R = \frac{qh\nu}{4\pi x^2} e^{-ux} \frac{u}{10.8 \times 10^{-9}}$$

where $qh\nu$ is the total energy given off as gamma radiation. Equation (2) can be written in a form which includes the effect of the neutrons as well as the gamma if the following assumptions are made:

(a) The gamma radiation represents about 1/18 of the total energy given off by fission; (b) the burst will occur in air, thus permitting the removal from equation (2) of the factor e^{-ux}; since ux is very small for air

[redacted]

and consequently $e^{-ux} \sim 1$, and (c) the fission neutron dose is about 3 times as effective as the gamma radiation[1,4]. The convenient form of equation (2) then becomes:

$$(3) \qquad R = \frac{6.18 \times 10^{-2} \text{ (energy of burst in joules)}}{\text{(distance from the burst in feet)}^2}$$

If the burst is surrounded by an attenuating material such as water, equation (3) would have to be modified to include the factor e^{-ux}. For example, 27 inches of water reduces this factor[8] to approximately 0.1. In addition, the equation would have to be modified to account for the attenuation of the neutron flux by the water.

Figure (1) was obtained from equation (3). Three air bursts are considered, a small metal burst of about 0.1 megawatts[1], a homogeneous solution burst of about 3 megawatts[3] and a large metal burst of about 15 megawatts[2]. These yield lethal radii of 1.5, 9.5 and 22 feet, respectively, assuming that a dose of 400 roentgen is lethal to 50% of the population[5].

An answer to the third question is given by Figure 2. Figure 2 is a plot of the residual radiation due to fission fragments from 0.1 megawatt burst. It is assumed that the gamma decay follows the $t^{-1.2}$ law, where t is the elapsed time[1] after the burst.

In order to answer question four, the following assumptions must be made: (a) the decay law for gammas emitted by fission fragments follows the $t^{-1.2}$ law[1], and (b) the number of gammas is directly proportional to the size of the burst. Now consider the following hypothetical situation. Assume that a burst occurs and an operator is standing only one foot distance from the burst. Let this burst deliver 300 roentgens of gamma and gamma-equivalent to the operator. Three hundred roentgens is probably sub-lethal. If the process monitor can detect a burst of this magnitude then it can be assumed that it will be adequate for all likely bursts. For this hypothetical case, the energy released

$$E = \frac{300}{6.18 \times 10^{-2}} = 4.85 \times 10^{3} \text{ joules}$$

If this energy is released in 0.2 sec., the power developed is 24,000 watts. It can be shown that the residual radiation one full minute after the burst is still sufficient to actuate a Y-12 process monitor 110 feet or more from the burst. Present Y-12 regulations state that no process monitor be required to cover a circle of more than 50 feet in radius. From the above considerations, this requirement is more than adequate.

For the burst described in reference one, a radiation level of 1.3 r/hr. was recorded 6.83 hours after the burst at a distance of 20 cm away. It was also shown that for an accident of 0.1 megawatt approximately 7 roentgens would be received by an operator who remains in the room for 20 sec. in addition to his primary dose. Thus, in this hypothetical case, an operator leaving the contaminated area in 20 seconds would not add appreciably to his total exposure.

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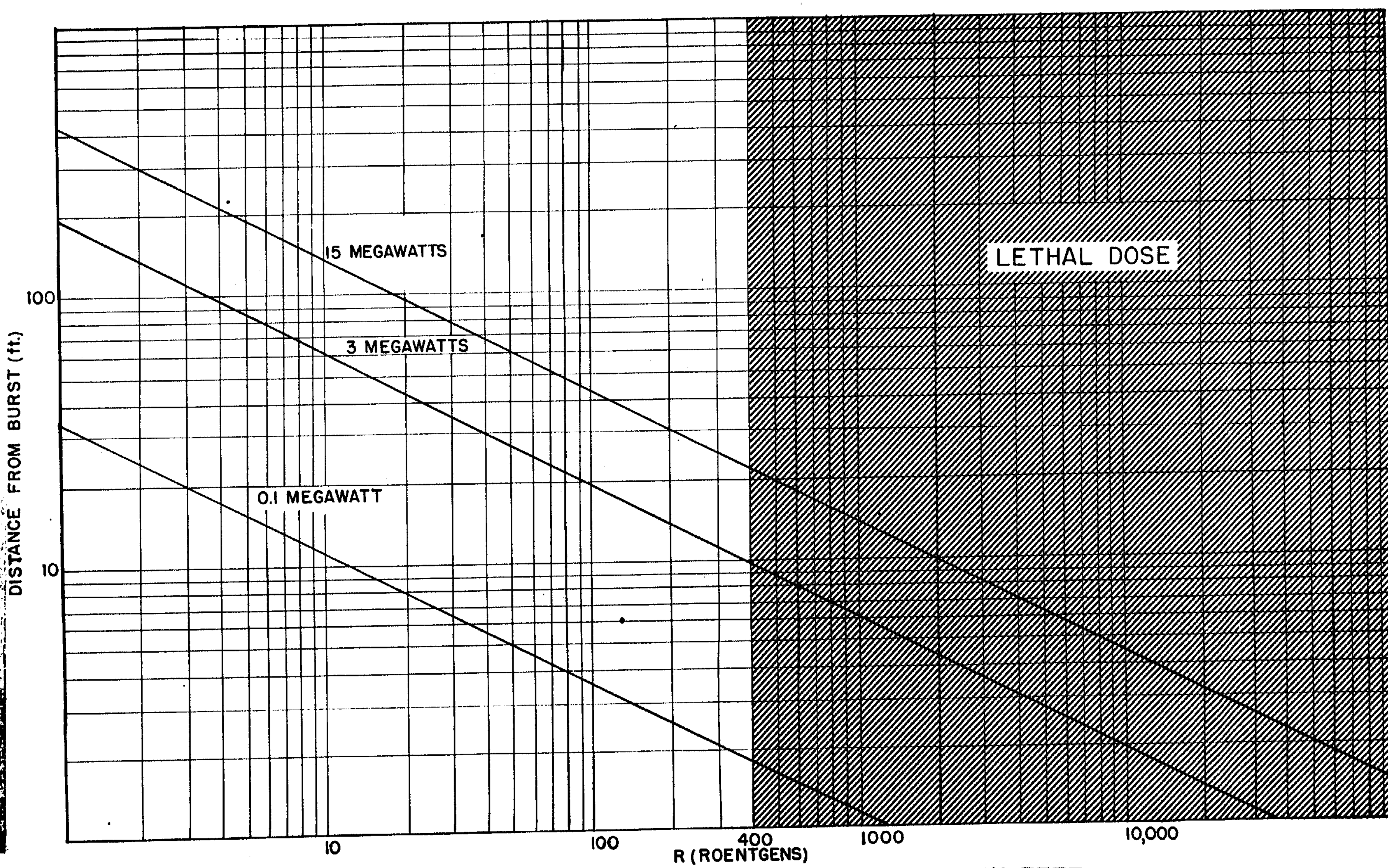

FIGURE I. RADIATION DOSE IN ROENTGEN vs. DISTANCE FROM BURST IN FEET

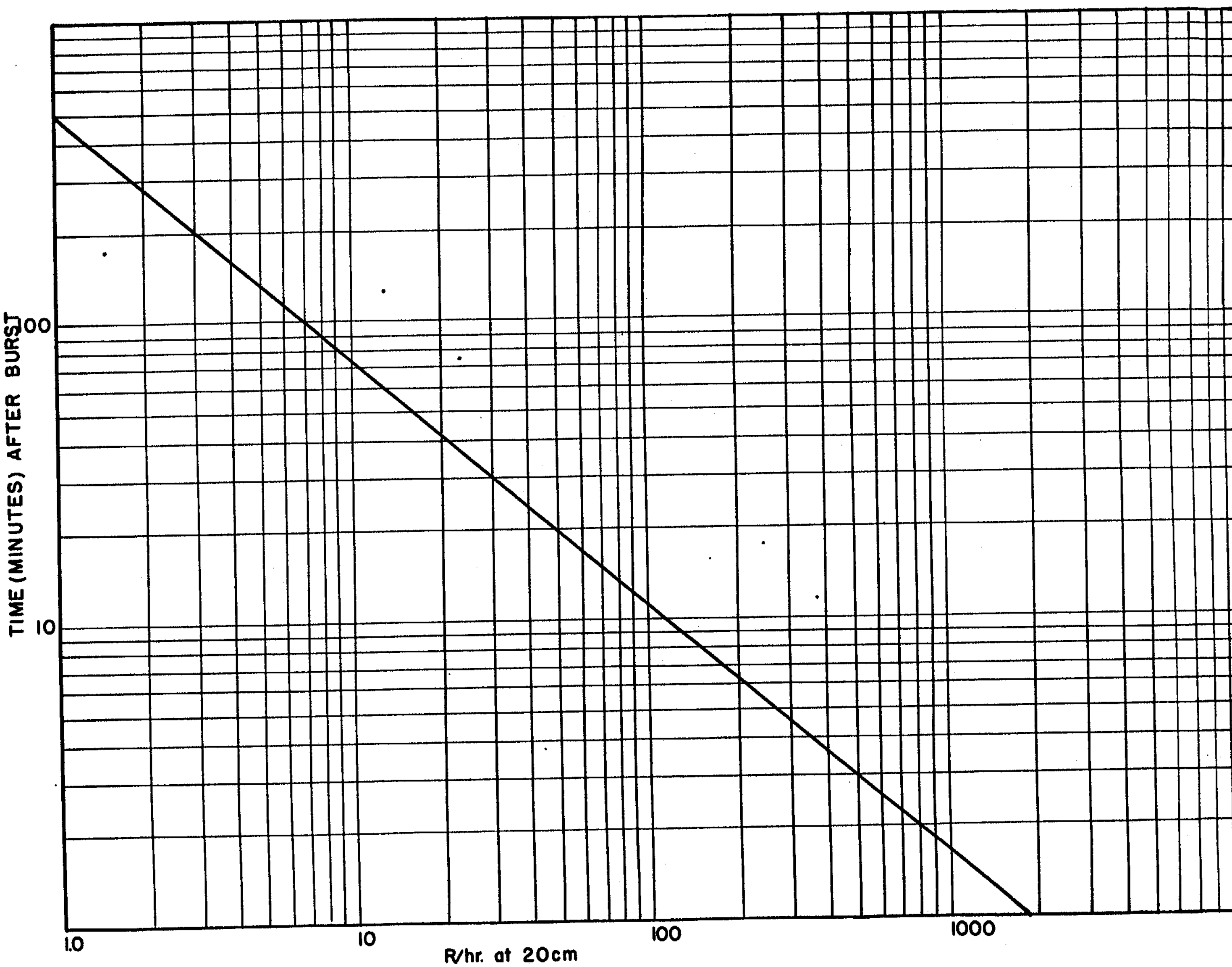

FIGURE 2. THE GAMMA RADIATION FROM FISSION PRODUCTS. RADIATION BURST OF 0.10 MEGAWATT.